Title of Project: Modeling and Analysis of Clinical Care for HIT Improvement

Inclusive Dates of Project: September 30, 2012– July 31, 2016

Federal Project Officer: Shafa Al-Showk

Acknowledgment of Agency Support: This project was supported by grant number R01HS021233 from the Agency for Healthcare Research and Quality. The content is solely the responsibility of the authors and does not necessarily represent the official views of the Agency for Healthcare Research and Quality.

Grant Award Number: 4R01HS021233-04 **Awardee:** University of Washington

Principal Investigator and Team Members

University of Washington
Keith Butler, PhD, PI
Mark Haselkorn, Ph.D.
Mark Oberle, M.D.
Amy Walker, R.N., Ph.D.
Brian Theodore, Ph.D.
Konrad Schroder, M.S.
Andrew Berry, GRA
Melissa Braxton, GRA
Christina Chung, GRA
Trevor Johnson, GRA
Nikki Pete, GRA
Tongfang Sun, GRA
Yi-Chen Sung, GRA

Veterans Health Administration
Jodie Haselkorn, M.D., M.P.H., Director, M.S. Center of Excellence, West, Puget Sound Health Care System
Walter Paul Nichol, M.D., Deputy Chief Medical Informatics Officer, Office of Informatics and Analytics

Baylor Scott & White Health
Yan Xiao, Director, Patient Safety Research
John Garrett, M.D. ED Medical Director

Brett Stauffer, M.D., VP Care Improvement
Adam Probst, Sr. Human Factors Specialist

University of Texas, School of Biomedical Informatics
Jiajie Zhang, Dean
Cui Tao, Ph.D.
Mohcine Madkour, Ph.D., Post-Doc

Criag Harrington, GRA

Brigham Young University
Eric Mercer, Ph.D, Lead for formal methods and model checking

Medico System, Inc.
Ali Bahrami, Ph.D, Development lead for Modeling & Analysis Toolsuite for Healthcare

Flying Squirrel Software
Chris Esposito, Ph.D, Developer for Patient-Centered Case Management System

Paragoge Software
Gary Coen, PhD. Development leader for natural language processing

1. Structured Abstract

Purpose Two challenges facing health information technology (HIT) are how to decide computing's appropriate role in clinical care, then design systems to improve care in predictable ways.

Scope We describe advances in workflow modeling, illustrate how they reveal appropriate roles of computing and then guide design of HIT systems that are highly usable and predictably beneficial. We modeled and analyzed care at three outpatient clinics: multiple sclerosis (MS) at a regional VHA clinic, chronic pain care at a large university medical center, and emergency care of another large university medical center.

Methods Baseline workflows were modeled with MATHflow, then analyzed for improvement with better HIT. Care complexity drove innovations to make modeling more powerful while simplifying flow diagrams:

- Intelligent decision gates that use information values to select workflow paths;
- Boundary events that coordinate behaviors throughout workflows;
- Conceptual work products that capture fundamental requirements and enable new methods for analysis, design, and verification;
- Verification of workflows that integrate HIT with manual care.

Results Beyond the workflow innovations, the resulting HIT systems include: Patient-Centered Case Management for MS; PainTracker for collection and analysis of patient pain data; Golden Sheet for pain procedure ordering; turn-around measurement for ED rooms; and natural language processing for ED decision support of admissions. All were implemented as prototypes and evaluated to verify usability by clinicians and by discrete event simulation for beneficial impact. The results demonstrate how HIT can improve care measurably and predictably.

Keywords health IT, workflow, MS, pain care, emergency care, evidence-based design, model-based design

2. Purpose

This research aimed to develop new techniques for model-based analysis and design of health information technology (HIT) systems, then demonstrate how they can be applied to design systems that are highly usable and predictably beneficial to care in outpatient clinics for multiple sclerosis, for chronic pain and for an emergency department.

The specific aims of the research were to:

- Apply ethnographic research to discover the way care is actually done with existing information resources at each clinic,
- Model research findings as baseline (*as-is*) workflows using the new modeling techniques of MATHflow,
- Analyze how care should be improved methodically in measurable ways with new HIT design concepts,
- Develop software prototypes of the most promising designs to evaluate usability, workflow impact, and technical feasibility,
- Refine MATH, our model-based design method based on experience with each successive clinic.

In addition, the project identified and published common design principles for workflows and health IT functions, posted work flow models as reusable libraries, and published user interface prototypes.

3. Scope

Electronic health records (EHRs) and associated applications of health information technology (HIT) have great potential to reduce health care costs while increasing efficiency and quality. However, EHR adoption faces great resistance due to large start-up costs, unpredictable benefits, and disruption to the workflow of clinical care[1,2].

A fundamental step to realize the potential of HIT is to decide the appropriate role of computing in clinical care. We define the appropriate role as functionality and information presentation that measurably improve care efficiency, quality or safety, in a manner that has predictable impact on care and is cost-effective to implement. Popular design methods for HIT, however, focus on software features without making a clear, predictable connection to the impact the aggregate use of features will have on clinical care. Until verifiable added value becomes routine for HIT its great potential will remain largely unrealized.

The model-based analysis and design method that was applied and refined for this research, closes the gap between HIT and predictable care benefits. It makes measurable benefits an explicit part of the HIT design process through model-based analysis and design technology.

Context of HIT Use

The term “health information system” is something of a misnomer because it’s work is actually carried out in an environment of distributed cognition[3], where information is used and changed by the by activities of clinic personnel and the information processing of computers. In this view HIT is one of many information resources in a care system where information is recorded, transformed, and shared. Like all resources, they constrain the way people can use them to accomplish their work. Research from cognitive science[4,5] and software design[6,7] consistently demonstrates that the content, organization, and representation of information necessarily impose powerful constraints on the way users perform their tasks. Cain and Haque described how HIT implicitly imposes workflow on nursing[8]. White and Miers argued that the software of an information system actually embodies a model of workflow, whether or not it was understood and planned[9]. Further, the impact is not limited to the immediate moments that clinicians interact with a computer. HIT constrains the way care is performed by controlling access, organization and format of the information that clinicians need to analyze, plan, and carry out treatment. The impact of these powerful constraints must be taken into account in order for HIT to produce predictable benefits.

Incidence

Organizations that represent clinical providers, such as the AMA, have repeatedly submitted Congressional testimony recommending a halt to regulations requiring further adoption of EHRs based on unpredictable and costly impacts, and increased patient safety risk[1,2]. The failures of HIT to produce predictable benefits for clinical care, or even contribute to negative effects care is well documented[9, 2, 10, 11, 12]. A practical obstacle to cost-effective EHRs is the lack of baseline standard clinical workflows across health systems or even within institutions that obscures needs, potential benefits, interchangeable process and reuse of software.

Settings

We conducted user research to discover current workflows with existing information resources, then analyzed how they should be improved with better HIT at three clinical settings in the following order:

- The Veterans Affairs Puget Sound outpatient clinic for multiple sclerosis outpatient clinic that sees about 400 patients each month.
- The Center for Pain Relief at the University of Washington in Seattle that sees about 1,200 patients a month.
- The Emergency Department at Baylor University Medical Center in Dallas that sees about 3,300 patients a month, with strong seasonal variation.

Participants

The study utilized 45 physicians, nurses and administrators recruited under IRB approved procedures to prevent coercion and protect privacy. Representative samples from each clinic role were recruited based on the organization chart of the clinic. As inducement to volunteer they were offered a twenty-five dollar gift card for each half-hour of participation. Based on their expertise some participants were recruited for follow-up sessions to clarify gaps or inconsistencies in the workflow models, to review models, or evaluate prototype HIT solutions.

4. Methods

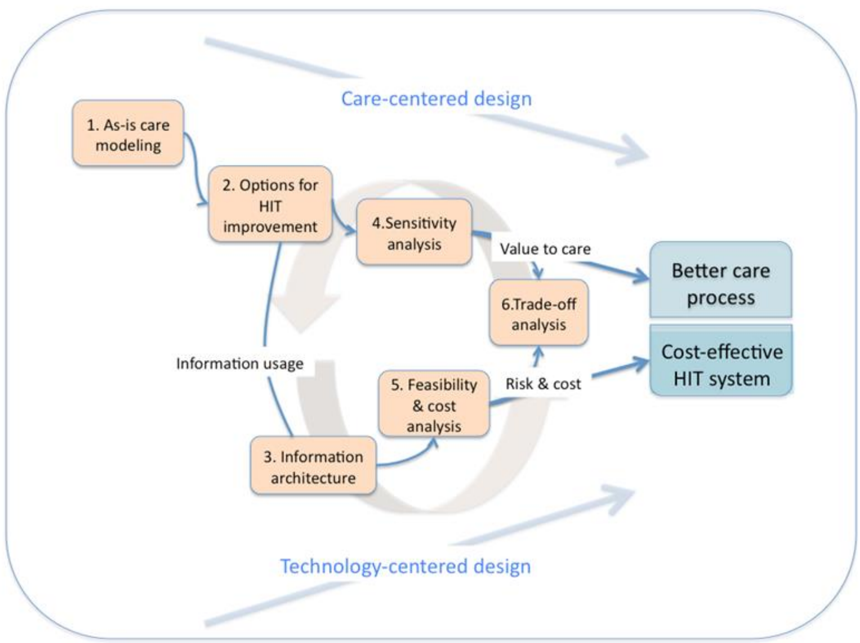
The overall project method was to capture and document how clinical work is actually done as baseline *as-is* workflow models, then analyze how better HIT could improve workflow in measurable ways. The method we applied, called MATH, is documented in detail in Butler, et al[12]. The method was repeated for each of the three clinics we studied in sequence. The three types of care were scheduled on the basis of expected increasing complexity of care operations.

MATHflow, the modeling tool of MATH[13], supports concurrent engineering of workflow and HIT. The success of concurrent engineering is well-established for physical products of the manufacturing industry[14]. Our findings illustrate how concurrent engineering for HIT systems can employ multidisciplinary teams to collaborate on a common system design, while each of the disciplines designs and advocates for their respective qualities, such as workflow efficiency, HIT feasibility, HIT usability, and cost-effectiveness.

MATH represents both HIT and workflow explicitly in a manner that makes clear how design changes in one constrain the other. Thus, MATHflow can be applied to converge the designs of workflow and HIT so they will work as a matched pair of system components for health care. MATH integrates "patient-centered design" with "technology-centered design" through iterations between a care-centered stream and a more conventional stream for software design. The result is a pair of matched designs that operate smoothly together as a measurably better workflow of care and highly usable HIT whose information flow maps clearly and efficiently to the needs of the better workflow[12]. The MATH-based method we employed to achieve this objective is summarized in Figure 1. The techniques and tools of MATH were refined to meet new needs to model complex care operations as we encountered them during the studies.

As is common for methods of model-based analysis and design there were three distinct but overlapping stages: 1) Acquisition of knowledge and data about how the clinic operates; 2) Encoding the findings as the baseline workflow using the MATHflow modeling language; and 3) Analysis of how the baseline model should be improved with better HIT to develop the *to-be* workflow. In practice, each successive stage revealed gaps and inconsistencies in our understanding that drove us back to earlier stages with focused questions about clinic operations and data.

Figure 1: MATH Method for HIT Systems



Knowledge & Data Acquisition

Clinic leaders served as points of contact to provide background for participant selection and recruiting. The privacy of each recruit was protected to avoid any coercion. Part of the recruiting invitation explained that a new computer system was being considered that could impact their work, and the interview was a chance to influence its design. In response, candidate participants showed very strong motivation and cooperation. Volunteer rates were more than ninety percent.

Interviews were scheduled for fifty minutes, with follow-ups as needed. In order to make efficient use of clinicians' time the topic of each initial interview was planned in advance. Interview sessions were planned for each of the use cases in each professional role in the workflow of care. Semi-structured interviews covered triggering events, the specific tasks they performed, and the resources where they accessed or changed information. Interviews were conducted by teams of one interviewer and one scribe. The interview included questions to identify problem areas and how the tasks should be done better. As each session concluded examples of work artifacts were obtained, the interviewer described the next steps to expect, and a phone number was recorded for quick follow-up questions.

Workflow Modeling with MATHflow

When interview sessions provided enough results we began workflow modeling with MATHflow. The translation of interview results into MATHflow often revealed gaps or inconsistencies in our understanding of clinic operations. We also used triangulation across participant interviews to detect inconsistencies. These gave us questions for focused follow up interviews. The interviews continued until data saturation was observed. When the models approached stability we held small group sessions to critique them.

MATHflow The Business Process Modeling Notation standard (BPMN) is a graphical language to capture and analyze requirements for information systems that support groups of people whose work spans physical and computer tasks [15]. MATHflow is a modeling tool that extended the standard to expose the role of HIT in health care. MATHflow explicitly represents the workflow tasks of clinicians along with the information resources that are required to support them. Although originally planned, standard names for nursing care activities were not useful because they were not adopted by either nurses in their practice dialogs nor by HIT developers in the applications we observed.

Information Modeling MATH integrates information modeling with workflow modeling by treating information as a type of resource needed by tasks. MATHflow has a property sheet for each task that allows analysts to enter the attribute name of the information that is required to begin the task, the resource where it was accessed, and the destination if the task changed its value. MATHflow has an information dictionary that automatically records all these relationships for subsequent flexible database queries. In this manner MATHflow captures information content, usage and flow as an integral part of a workflow model.

We abandoned plans to use standard data definitions because none appeared in HIT applications we observed, and used the terms found in documents and applications. In all clinics we observed a variety of types of information resources being used to access, record or generate information. They included paper documents, HIT, reader boards driven by HIT, whiteboards, mechanical devices, clinical personnel, and patients. These were represented explicitly as types of information resources in the model. The resulting information dictionary provided a key set of requirements for the Analysis & Design Stage.

New MATHflow Features As we encountered more complex operations that needed more powerful modelling capability we added them as new features to MATHflow:

- Intelligent decision gates to select workflow paths based on the value of information variables from anywhere in the model. This feature provides the capability to model common situations in which new information from one part of a workflow must govern decisions in other parts. Intelligent decision gates also simplify the graphic density of workflow models[16].
- Boundary events that coordinate behaviors throughout workflows. For example, in ED care nurses typically continue performing orders until receiving word that new orders have superseded them. After some interval a doctor will issue the new orders from a work stream that is parallel to the nurse’s and the nurse will switch to following them. MATHflow can represent this complex situation by placing a boundary event on the nursing task that catches the message for superseding orders[16]. Boundary events also simplify the graphical density of workflow models.
- Conceptual work products (CWP) that capture fundamental requirements for conceptual work. When the health care work being modeled is substantially cognitive, tacit, and complex in nature, graphical workflow models become too complex to be useful to designers. CWP complement and simplify workflows by providing an explicit specification for the information product a workflow they must produce, such as treatment plans or case management. CWP can be modeled using complementary class diagrams and state diagrams. They provide fundamental requirements for the entity that a workflow must accomplish and the information that a new system should provide. Developers can use these specifications to envision how health IT could enable an effective cognitive strategy with precise information requirements[17].
- CWP can also serve as a new form of evaluation criterion that enable powerful, automated model-checking tools to verify the effectivity of designs for human-systems integration[18]. The interaction of clinicians with HIT

and with other clinicians creates workflows that are very complex. The models need to be checked to verify that the design will actually do the job expected of them, or identify where in the workflow it will fail.

Download links to the MATH software, documentation, and training material are at http://parvac.washington.edu/nccd/download/docs/.

Analysis & Design

The purpose of this stage is to determine how problems in the baseline workflow should be improved in measurable ways with better HIT. Our focus was on problems arising from use of existing information resources, as summarized in Table 1 below. Each of the compensation examples in the right hand column resulted in unplanned overhead tasks, communication problems, delays in patient care, or increased error risk.

Table 1: Summary of Observed Information Problems

Information Resource Problem	Clinician Compensation Examples
Information has different values in multiple, redundant resources.	Check to determine authoritative source. Manually maintain consistency.
Sequence of access doesn't match workflow.	Transcribe onto paper and reorganize.
Needed pieces of information are spread across resources.	Transcribe onto paper, then integrate by hand onto notes.
All information is in a display all the time.	Scanning, ignoring cluttered pages. Alert fatigue.
Right information content but wrong format.	Sketch to transform to needed format. Mentally transform or estimate.
New information is expected but time is unknown.	Checking, and re-checking. Post-It Note reminders.
Information may be out of date.	Checking other sources. Calling. Guessing.
Partial automation to manage information.	Re-do some tasks manually to overcome fractured awareness.

<u>Better Satisfaction of Information Requirements</u> The method of analysis and design involved editing the baseline model into the "*to-be*" model by replacing problematic information resources with models of better HIT that removed or mitigated the current problems. MATH treats information as a type of resource, thus allowing tradeoff analyses of better information for less use of other types of resources, such as the time of a skilled clinician carry out appropriate protocols. The information requirements identified in the dictionary were satisfied but with a new information architecture that eliminated or mitigated problems in the workflow. In several cases the workflow was reengineered for benefits beyond problem remedies. The editing was conducted using techniques for concurrent engineering[14] to co-design clinicians' tasks and workflow with emerging HIT designs through iterations so they would converge and work together as complementary parts of an integrated system.

<u>Design Evaluations</u> We followed an HIT evaluation strategy that began prior to the time major design decisions were made. It incorporates both long and short-term effectiveness and efficiency outcomes that result from improvements in clinical care workflows[18]. This strategy starts with a value proposition for the desired impact of the proposed HIT intervention. Candidate designs were evaluated for improvement of workflow, usability, better adherence to appropriate practice, and for the technical feasibility of implementation. The evidence we gathered was simplification of workflows, discrete-event simulations of the workflow models, usability evaluations of user interface prototypes, and technical feasibility analysis of software prototypes. Time duration was the main measure we recorded for tasks and for overall flows. Quality was defined in terms of adherence to appropriate practice.

Discrete-event simulation is a well-established method to evaluate resource needs of plans or designs[19]. MATHsim is the discrete-event simulation engine that runs on MATHflow models[20]. The MATH technique of modeling information as a resource allowed us to conduct trade-off studies of better information for less use of other resources, such a time or labor. Good correlation between actual and predicted impact of HIT on workflow was reported in earlier studies[13]. We ran MATHsim to estimate each HIT concept's impact on the work burden of clinicians, delay reductions, and the end-to-end duration of workflows. The reuse of models allowed us to develop and quickly evaluate multiple solution options before developing prototypes.

Prototypes of user interfaces were designed to clarify design details, and evaluated to estimate impact at the task level, then to verify or refine usability[21,22]. We applied model-based cognitive task analysis to obtain estimates of task steps and task times[23, 24] and used them to compare user interface options before developing them more fully in software. Data from the usability tests we conducted showed strong concordance with model predictions[17]. User interfaces were also evaluated by subjective surveys[25] and expert reviews.

Limitations

The biggest limitation to the MATH method is access to busy clinical personnel for interviews. We mitigated that risk by advertising a chance to influence HIT systems they might have to use, and by preparing interview plans in advance to use available time efficiently. The duration of each stage for interviews was 6-8 weeks, but could be much shorter in non-IRB projects. Another limitation is the broad, multi-disciplinary expertise needed
By the project team: a project physician, nurse, ethnographer, modeler, and software developer. A third limitation is the quality of MATH software, which is available for free beta use but is not supported as a commercial product.

5. Results

The results are in two forms: 1) The principal findings are the system design concepts that were implemented as prototypes; 2) The outcomes are the evidence that supported the decisions leading to their design and the formative evaluations that predict care benefits. Five HIT system prototypes were modeled, designed and evaluated to address the needs of: 1) Case management for MS; 2) Procedure ordering for pain care; 3) Patient data collection and analysis for pain care; 4) Room turn-around measurement for ED care; and 5) ED decision support for admissions. The models and information dictionaries are archived on the project web site at https://depts.washington.edu/ahrqserv/

Patient-Centered Case Management System for Multiple Sclerosis (P-CMS)

Workflow analysis revealed case management is a critical role at an MS outpatient clinic that cares for about 400 patients every four months. MS patients have many complications and about 60% are in wheelchairs. Providers issue orders in about 90% of exams and the treatment plans are often complex, with as many as ten orders for tests, evaluations and treatments by different disciplines. There are at least eleven distinct types of orders for prescriptions, tests, therapy, or specialist consults. All order types have their own distinct steps and courses for timely completion. The majority of outpatient care takes place during the interval between clinic visits, but MS symptoms pose serious obstacles for patients to carry out their treatment plans. E.g., only about 50% of lab tests and x-rays are completed on the same day as the clinic visit. A senior RN is assigned as case manager (CM) to manage the timely completion of the treatment plans between visits. CM also serves as patients' point of contact for any new problems.

In the current EMR there is no specific support for case management. In addition to the medical complexity, the CM must currently monitor and manually integrate information from at least six, overlapping information resources. We observed remarkable dedication and conscientiousness on the part of the CM to provide high-quality case management. However, due to inadequate information resources to support it, this dedication came at the price of sustained high effort to compensate and high stress about risk for losing track of cases and orders.

<u>Solution Approach</u> We integrated the information in a new HIT system called Patient-Centered Case Management System (P-CMS) [17] and designed a user interface that reorganized the information around four groups of patient-centered questions that allow a strategy of management by exception:

1. Which of my patients have new orders? Are their prescriptions accurate and consistent with drug allergies?

2. Which of my patients has a treatment plan that is not progressing satisfactorily? Which of the orders are hung and why? Is intervention needed? If, so, who was the last person that handled it and what is that phone?
3. Which of my patients have an exam appointment coming up? Are they going to attend? Are all their orders resolved? If not, which orders are not?
4. Where is the record of this patient who just called to answer questions or note an action item to get back to him?

Figure 2 shows the home page of the user interface (UI). We used the familiar metaphor[26] of stacked medical record files for design of the visual layout. The underlying database integrates previously disparate information for the user. The filters at the top of each column allow the user to sort and re-sort the patients by name, last or next visit date, and the age of any lagging order in their treatment plan. If any order is falling behind timely completion it is displayed in red.

Figure 2: Home Page of Patient-Centered Case Management System

<u>Evaluations</u> A simulation of the workflow enabled by P-CMS estimated a time savings of about 4.5 hours per week for the CM. We conducted a summative usability test of the prototype with eight senior RNs from another clinic to validate whether the design is used as planned. The most important finding was with few exceptions the test users performed their procedures with P-CMS as they were designed. Figure 3 shows the time it took for participants to finish each scenario. Numeric labels on the bars indicate the average time in seconds, and bars show the standard error of the estimate.

Figure 3: Usability Evaluation Results

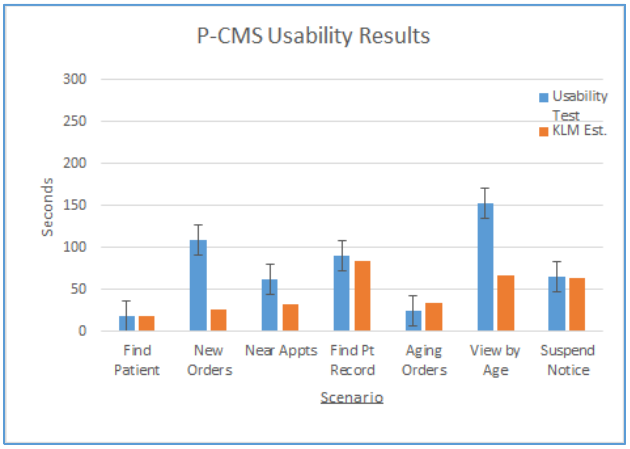
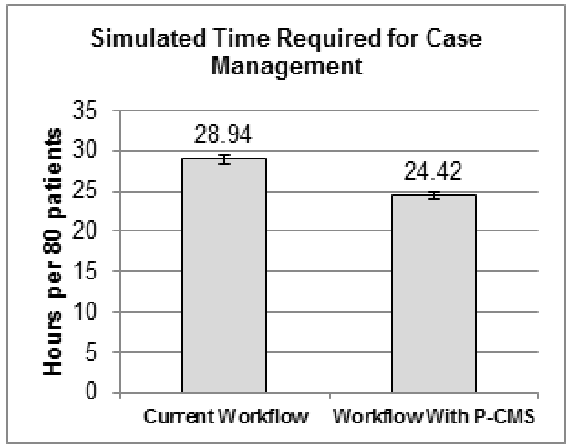


Figure 4: MATHsim Results of Workflow Impact



The prototype has above average usability based on the SUS[25] score of 71.8, with scores above 68 are considered to be above average. The usability data are consistent with participant verbal reports that the interface was "easy to learn" and that it was "easy to find what they needed."

The time values of the usability test were used to revise the *to-be* workflow model, then MATHsim was run to estimate the overall time savings impact of P-CMS. The results are shown in Figure 4. The fifteen percent savings equals well over a full hour each day to spend on patient care. The impact is more than time savings, it will allow case managers to work more at the top of their skill levels, have greater situation awareness, and far less job stress.

The technical feasibility of P-CMS was demonstrated with a fully functional prototype. The feasibility of accessing the needed data from the daily Regional Data Warehouse (RDW) at the VISN-20 was analyzed by developing a table of links between each data definition in the P-CMS database to those in the warehouse[17]. We then developed a test database using fictional data to mimic the warehouse and to demonstrate how RDW feeds can satisfy P-CMS. The RDW feeds would enable near real-time surveillance of MS patients using the P-CMS tool for clinical orders, lab results, radiology results, consult and appointment tracking.

Status A version of P-CMS that was revised based on usability findings has been implemented as a fully functional web-based application with a database of anonymized patient data. P-CMS was developed for a specific CM in a MS clinic, but we anticipate that this design is generalizable for case management of other chronic diseases. The revised version is demonstrated in a video at http://depts.washington.edu/ahrqserv/docs/P-CMS_demo.mp4.

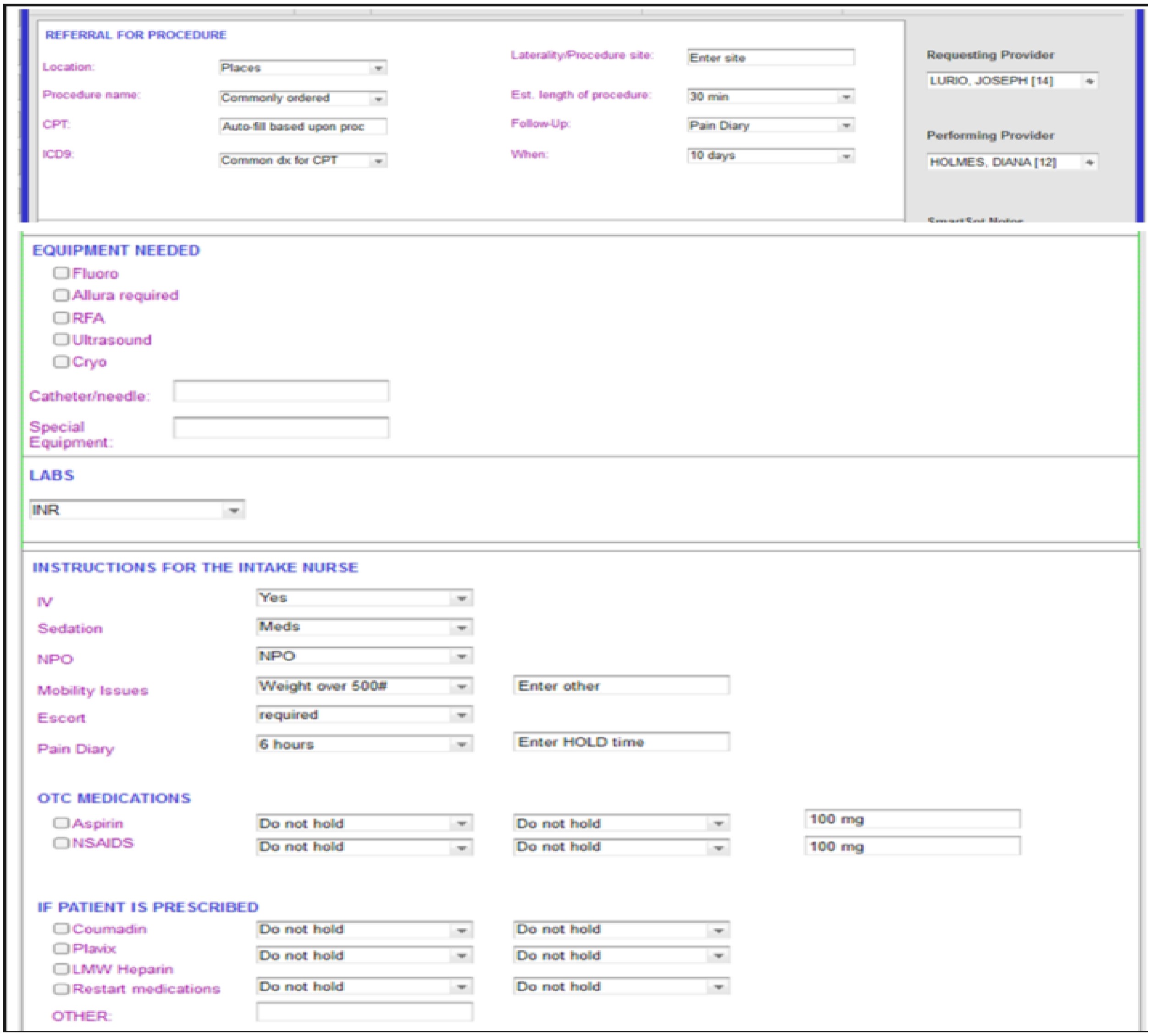
Golden Sheet for Pain Procedure Ordering

We modeled the workflow of care at a chronic pain clinic two months before they adopted the EPIC Care outpatient EHR, then again one month after adoption. We observed that Epic Care's module for computerized entry of procedure referrals introduced substantial extra work and delays. Before Epic, a yellow paper form played a central role in the way physicians created procedure referrals and staff scheduled, and managed them. After the clinic started using Epic, however, physicians reported that it took them much longer to enter new referrals, compared to the time it took them to fill out the yellow form. The Epic Care procedure referral user interface is a collection of text and asterisks. It functions as a list of important information that should be relevant to a procedure order. The ordering provider must use tabs or function keys to move through the list awkwardly towards points of decision. Unfortunately, this Epic Care user interface, meant to replace a hard copy procedure referral, has increased the workload of the CPR doctors and nurses and created redundancies in information processing. The problem was severe enough that physicians stopped using Epic Care for ordering procedures and reverted to their old process of filling out the yellow procedure referral form. The extra work of entering referrals into Epic Care then fell to nurses.

Solution Approach We determined there was customization capability called SmartSets available in Epic Care that could be configured for a better user interface to enter procedure referrals, shown in Figure 5. SmartSets can change user interfaces without changing the source code of the EHR. However, analysis of the entire workflow for handling procedure referrals revealed that the yellow form was used for much more than just creating procedure referrals. Front desk staff used the form to schedule the referral, the financial care coordinator used the form to secure insurance authorization for the procedure, and after front desk staff had scheduled the referral, nurses again used the form to notify patients when to stop taking medications. The design solution needed to support all the user types in the workflow, and not only the physicians at the expense of more work for staff.

We designed an effective solution with two “work queues” in Epic that are fed by the new Smart Sets user interface

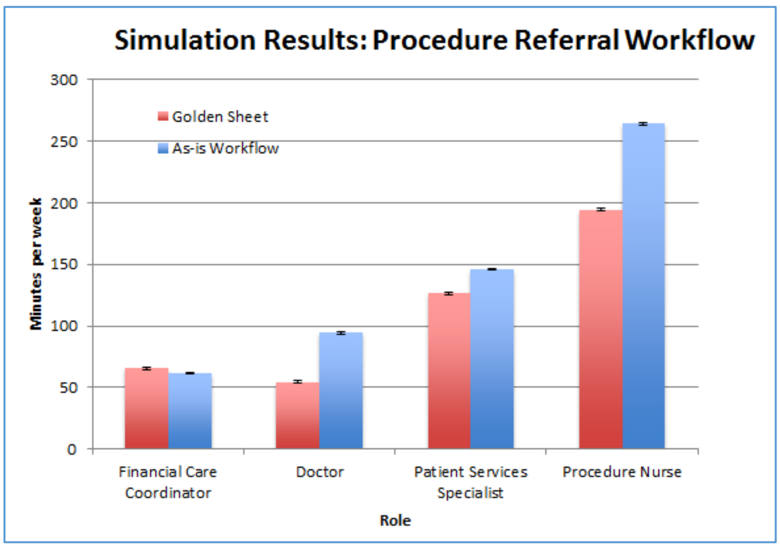
. Figure 5: Improved UI for Procedure Entry



The new workflow was also more efficient because the financial care coordinator no longer has to enter procedure referral details into Epic. As shown in Figure 5 the user interface for orders has defaults that allow the physician to place orders for procedure referrals as quickly as they could with the paper form. The new user interface has procedure identification, procedure orders, and referral routing capabilities. It does most of the current repetitive work by recording and displaying commonly used procedure information, equipment, labs, and instructions for the intake nurse. Providers can select procedure data from drop-down lists or use auto-completion. The workflow continues with automatic notification to the financial care coordinator that referrals need insurance authorization, and then notifying the procedure nurse that patients need to be notified of medication holds. Creating work queues in Epic provided these functions by organizing the necessary information in one place where the financial care coordinator and procedure nurse can see what action is needed and the information needed to complete that action. Each of the new user interfaces in the work queues has a “forward to” selection menu to control the next recipient in the workflow. The recipient then takes responsibility for that step by selecting “accepts” on the form.

Evaluation & Current Status The improved design was simple enough for initial usability evaluation by doctor and staff reviews that were very favorable and led to only minor revisions. The predicted impact on the workflow of care is shown in Figure 6. The results indicate a substantial workflow improvement for Golden Sheet over native Epic Care of about eight hours every week. The standard error values (top of each bar) are quite small. These work time-savings are pivotal for both patients and the clinic. It means that insurance authorization for procedure referrals can be processed more quickly, appointments can be scheduled earlier, and care can begin sooner.

Figure 6: MATHsim Results for Golden Sheet Impact



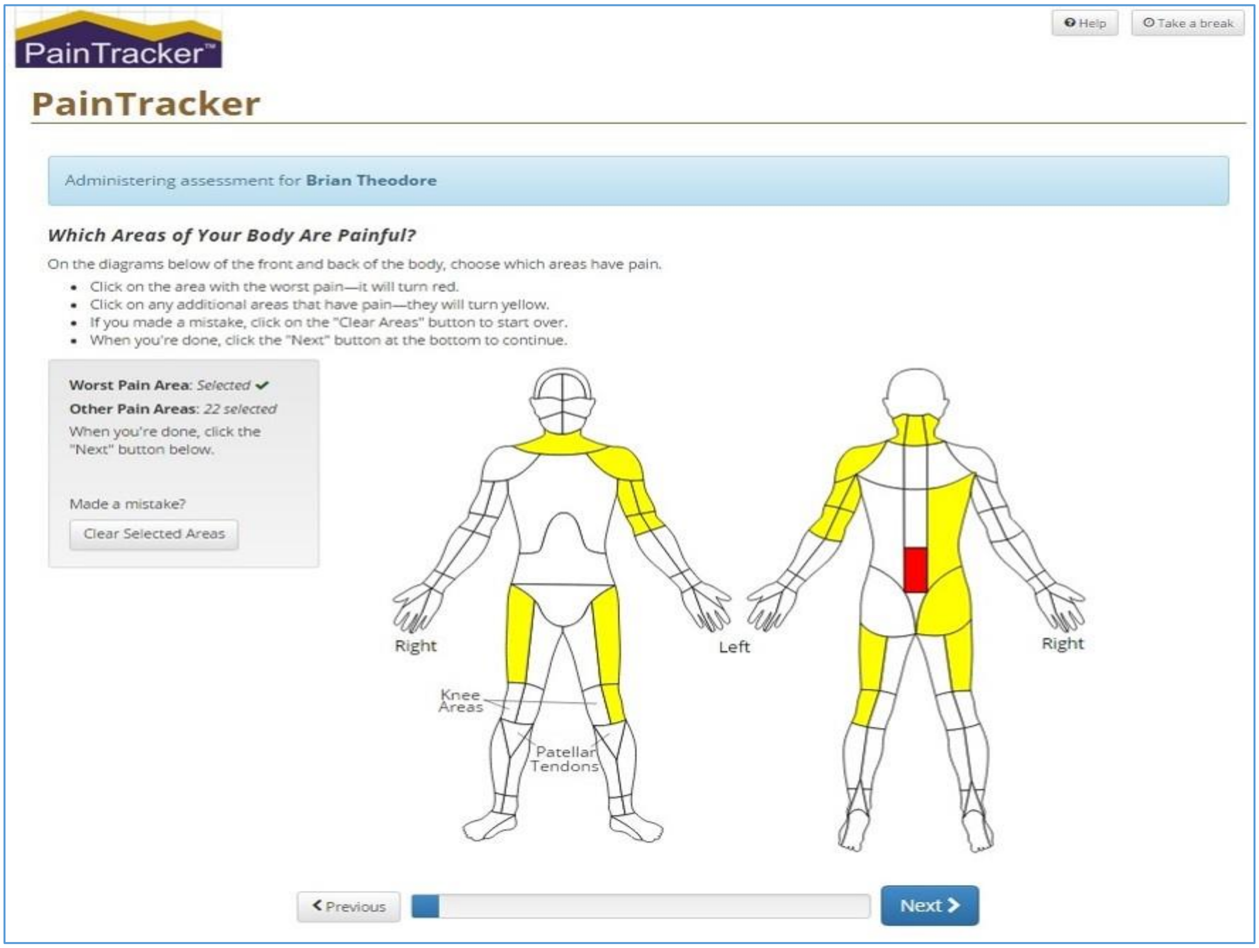
The benefits also improve clinic income because procedures are an important source of revenue. Golden Sheet illustrates how understanding the impact of HIT on the workflow can lead to designs with wider benefits.

The technical feasibility of the prototype allows fast, economical implementation by creating it in Smart Sheets, which can be imported directly to the test version of Epic Care for verification further testing, then moved to the operational version with little effort. Golden Sheet is currently waiting in the change request queue.

PainTracker

The Pain Clinic also uses PainTracker, a web-based tool to obtain patient pain data and then graph and assess core patient-reported outcomes of chronic pain management[27]. PainTracker is an important tool to protect patients from harmful use of pain medications. A key self-report screen for the patient is shown in Figure 7. PainTracker provides displays for providers, such as Figure 8 for quick evaluation of patient progress over time and to support treatment planning, including the relationship between chronic pain treatments and outcomes, such as pain, function, mood, sleep, and treatment satisfaction. PainTracker was implemented as a web-based application on the Computerized Patient Reported Outcomes platform by the UW Center for Informatics Research. When used with Epic, however, the workflow for PainTracker was awkward, requiring multiple different information resources to complete a patient assessment: The Epic Cadence Scheduling Database, the Patient Check-In Module, EpicCare, PainTracker self-assessment, the patient’s copy of PainTracker report, and the provider’s copy. In total, approximately 47 steps were needed in the workflow, beginning with the patient referral to the through their first follow-up appointment. These bottlenecks in workflow, coupled with high volume of visits, required the support of a dedicated FTE in the clinic.

Figure 7: Example Patient Screen of PainTracker



<u>Solution Approach</u> Our analysis of the workflow model confirmed three requirements for data interoperability between Epic Care and PainTracker: (1) a data feed from the Epic Cadence Scheduling Database into PainTracker to automate cross-checking PainTracker completion with upcoming appointments; (2) flagging patients for reminder phone calls if they did not complete PainTracker; and (3) feeding Epic Care with a digital copy of the PainTracker report for provider use. The situation required a clever approach to support the needed workflow.

For scheduling data, screen scraping the rolling two-weeks of the Epic Appointments Report could be fed daily to PainTracker. Flagging patients for appointment reminder calls is part of a routine task for the patient services coordinator (PSS) for checking approaching appointments in Epic Cadence Scheduling. The PSS follows a procedure that involves checking each of those patients in PainTracker for "recent enough" survey completion dates before making the reminder call. For the provider report, a .pdf file was generated automatically and sent to Epic Care, where it appears in the Media Tab for of the provider's user interface. These techniques enabled a complete workflow to support PainTracker for far less effort.

Figure 8: Example Provider Report of PainTracker

	7/11	7/21	7/25
Days w/ Excess Meds (past month)	3 - 4	3 - 4	5 or more days
Important Activity	testing	Walking	
Difficulty Level (0-10)	7	7	2

Side Effects (Self-reported from most recent assessment: 7/25/2014)

Sickness

Prior Treatment History (In last 6 months—reported in initial assessment)

Providers Seen	
Primary Care	5
Pain Specialists	2
Surgical Specialists	2
Medical Specialists	8
Psychologists/Psychiatrists	5
Physical Therapists	3
Complementary/alternative Medicine	3

Treatment Effectiveness	
Phys/Occupational Therapy	It was moderately effective
Heat, Massage, TENS	It was very effective
Behavioral Treatment	It was very effective
Non-opioid Meds	It was moderately effective
Alternative Therapies	It was very effective

PTSD (Reported in initial assessment)

Have had nightmares about it or thought about it when you did not want to?	Yes
Tried hard not to think about it or went out of your way to avoid situations that reminded you of it?	Yes
Were constantly on guard, watchful, or easily startled?	No
Felt numb or detached from others, activities, or your surroundings?	No

PainTracker Item Responses (Self-reported from most recent assessment: 7/25/2014)

PHQ-9	
Little interest or pleasure in doing things	More than half the days
Feeling down, depressed, or hopeless	Several days
Trouble falling or staying asleep, or sleeping too much	Several days
Feeling tired or having little energy	Several days
Poor appetite or overeating	Several days
Feeling down, depressed, or hopeless	Several days
Trouble concentrating on things	Not at all
Slow or fidgety	Not at all
Thoughts that you're better off dead	Nearly every day

GAD-7	
Feeling nervous, anxious, or on edge	Over half the days
Not being able to stop or control worrying	Over half the days
Worrying too much about different things	Over half the days
Trouble relaxing	Over half the days
Being so restless that it's hard to sit still	Over half the days
Becoming easily annoyed or irritable	Over half the days
Feeling afraid as if something awful might happen	Over half the days

PT.NO:

GRANTHAM, JACK

DOB: 1974-07-31 SEX: F

UW Medicine
Harborview Medical Center — Northwest Hospital & Medical Center
Valley Medical Center — UW Medical Center
University of Washington Physicians Seattle, Washington
PainTracker
Page 2 of 2
U0000
U0000
WHITE - MEDICAL RECORD
UH0000 REV MAY 14

Evaluation & Status The new version of PainTracker reduced worktime so much that one entire FTE could be reassigned to more interesting and productive work. The new workflow did add short, distinct tasks for the PSS that totaled about twenty-eight minutes per week. The new workflow illustrates the value of being able to make tradeoffs with a model that makes tasks and information explicit. Paintracker has been in operational use since July, 2014. Between then and June 2016, there were 2,920 unique patients who used it and a total of 6,231 assessments were completed (both new and returning patients). During this time, patient compliance rate for completing PainTracker improved by almost 50% for all new patients seen at the clinic. Averaging across the first three quarters evaluated (Jul 14 – Sep 14) versus the last three quarters evaluated (Apr 16 – Jun 16), the increase in compliance was still substantial, at 40%. For returning patients, this quarter-to-quarter comparison indicates a 124% increase in compliance. Clinics for sports medicine and the regional trauma hospital have specific plans to adopt PainTracker. PainTracker also serves as the core of outcomes assessment in three recently funded studies by the Mayday Fund, Pfizer Independent Grants for Learning & Change, and the Patient-Centered Outcomes Research Institute.

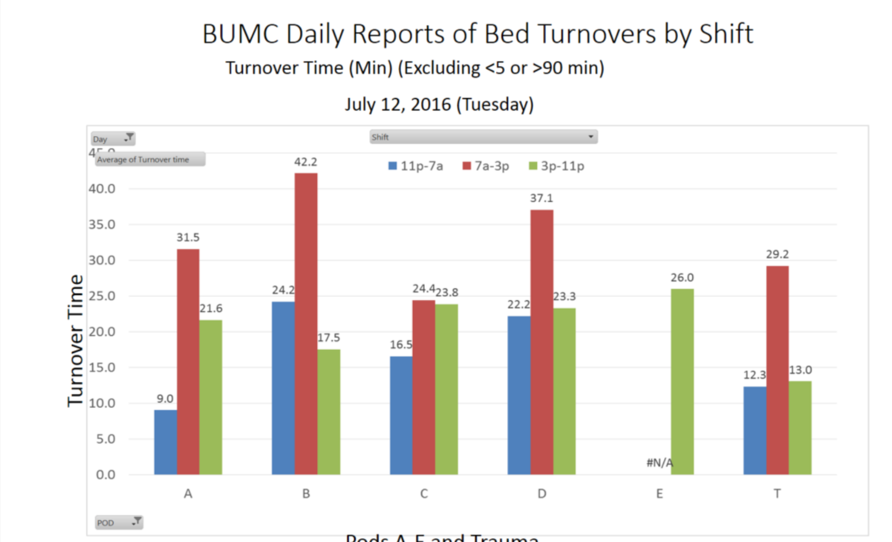
Emergency Department Room Turnover Metric

Workflows identified a key bottleneck in the Baylor University Medical Center's Emergency Department (BUMC ED) for timely placement of patients in exam/treatment rooms. The cause of was uncertain, and the ED management team lacked any performance metric to analyze how to reduce delays in patient placement (i.e., room-turnover times). Published literature on key ED performance metrics[28] has been patient encounter-based, starting with the arrival of a patient and ending with the patient's departure from ED. Room turn-over times, however, are not associated with a given patient's visit to the ED, but rather with an aggregation of patient data. Current reporting functions for MedHost, the ED EMR, do not include room-turnover times.

Method Initial analysis concluded that the needed data were not recorded in MedHost, but a review of the information dictionary in the MATHflow model of ED workflow indicated that the data must reside in MedHost. A feasibility study was conducted to locate the time-stamped event data in MedHost. We found data for the event when a room was marked dirty upon transferring out the patient, and data for the event that reassigned that same room to a new patient. Room room-turnover time was then calculated as the interval between those events (i.e. the time interval between an exam/treatment room being marked from 'dirty' to clean' in MedHost). The study demonstrated it was feasible to identify the needed data elements recorded in the existing MedHost database, and to extract the needed values.

For the initial demo we manually calculated room turn-over times by bed location, day of the week, time of the day, along with their descriptive statistics (e.g., median and inter-quartiles), broken down by ED treatment area (i.e. pods). Figure 9 shows a version of the daily report now being trialed in daily ED leadership meetings. Error bars represent one standard error.

Figure 9; Mean room turnover (in minutes) by pod.



# of Turnovers

	A	B	C	D	E	T
11p-7a	7	14	23	16		8
7a-3p	8	26	18	15	1	6
3p-11p	6	7	25	15	6	6

In order to eliminate accidental entries of bed status the data only include intervals between five minutes and eight hours to eliminate accidental entries and a pod shut-down (longer than eight hours). Room turnover for each ED pod was calculated as the average time interval, i.e., the sum of intervals divided by the number of pod room turnovers. These data are displayed as the median room turnover time by pod per day, and the mean time by pod per month, including the total count of room turnovers.

Status The content and format has been revised based on trial feedback from ED leadership, including use of the reports in daily staff huddles. The strength of the approach was to identify the relevant time-stamped events in MedHost, then download the associated data for flexibility to trial and revise prototypes. This study highlights both the importance and feasibility of aggregate patient data to analyze ED performance improvements. The specifications for data and displays have been submitted by ED leadership to MedHost as a change request that should be valuable to many EDs around the country.

NLP Decision Support for Admissions

The BUMC workflow model also revealed substantial delays due to uncertainty about the appropriate hospitalist or specialist to request an admission. In addition to specialists the ED uses two groups of hospitalists: MedProvider and Texas Primary Care (TPC), which is the default accounting for about 50% of all admissions from the ED. Often patients cannot provide the needed information for an ED MD to make an accurate decision about which group to contact. Relevant patient information is often stored in either MedHost, the ED's EHR, or in Allscripts, the hospital's EHR. No single information resource summarizes the information to support this key decision-making, so ED MDs must spend time searching. If no relevant information is found, then TPC is the default choice. This produces a decision bias. ED MDs often spend time trying to confirm that there is no relevant information, which is a task that is open-ended, inherently inefficient, error-prone and frustrating. About 33% of work-ups for TCP by admitting MDs turn out to be mistaken. The negative impact is more than wasted time by ED MDs searching for data that may not be there, it causes delays to begin the patient's hospital treatment while mistaken work-ups must be discarded and an MD from a different group must start over to create a new work-up.

Solution Approach Based on interviews, observations, and EHR inspections, we defined the information types that are relevant to select admitting MDs, then developed a natural language processing software prototype to prove the technical feasibility of automated extraction of the information types from digital text. Figure 10 illustrates partial results of the physician name-spotting algorithm tested against an anonymized test data set of 889 discharge orders[29]. A sample of test records was reviewed by BUMC MDs and judged similar to patient records they must currently search manually. Some patients have over a dozen discharge records that range from one to nine pages.

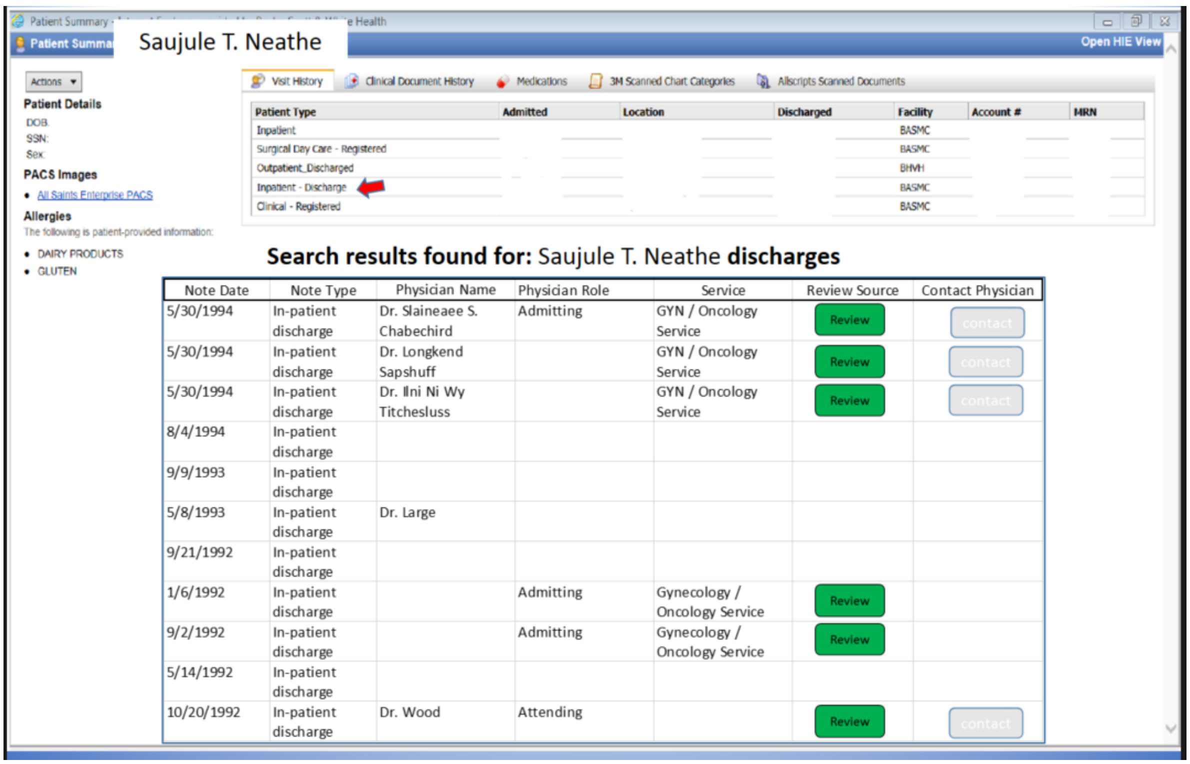
Figure 10: Example patient record with NLP-found Provider (**in bold**)

IN SUMMARY :
She also has a low-grade fever of unknown etiology , has a background history of deep venous thrombosis and is therefore currently on anticoagulation and she shows evidence of dehydration and failure to thrive .
It was decided at that time to hold off with the chemotherapy .
HOSPITAL COURSE :
The patient was therefore admitted to the GYN / Oncology Service under the care of **Dr. Chabechird** .
Laboratory tests were repeated in view of some of the above abnormalities and was remarkable for sodium 138 , potassium 4.0 , BUN and creatinine remained elevated at 36 and 2.8 respectively .
Urinalysis showed 10-20 white blood cells .

We analyzed the raw text of the test data set to determine word frequencies, mutual information, collocation frequencies, and other association metrics. This provided a window into meaning and usage[30]. Next, we correlated targeted information elements with variable text segments distributed in the corpus, noting the pattern of variability exhibited by textual instances of each information target. Then we created regular expressions to capture the variable patterns of targeted information[31]. Finally, we compiled these regular expressions into finite-state recognizers and applied the recognizers to designated texts[32]. This process extracted the desired information, presenting each extract as a physician name, role, consultation, or other relevant detail.

Figure 11 shows a mock-up of a user interface to illustrate how the results can be summarized in a highly usable, interactive format. The prototype demonstrates how the NLP information extraction algorithm can provide physician names, roles, consultations, and other details relevant to hospital admissions from large volumes of electronic health records, then summarize them in a usable format. The results also capture the immediate context surrounding the target if the physician desires to view it for verification.

Figure 11: Mock-up of NLP user interface



The left column organizes the records found for the identified patient by chronological order, whether or not they contain relevant information. Extracted target information is displayed in columns labeled Physician Name, Physician Role, and Service. The green button links back to the portion of the source text where the named physician was found. As shown in Figure 10 this context allows the user to review and verify the information's accuracy. The grayed-out buttons in the column labeled Contact Physician would call the appropriate physician from the user's computer using voice over internet protocol.

Status The burden of finding and extracting information that is relevant to a decision but distributed throughout patient records is a common situation in clinical care. Our NLP approach extracted this information without the labor and expense of conventional machine learning methods, which require an iterative annotation cycle to compile, mark up, and test a gold standard corpus upon which to train algorithms[33]. The technical solution to this specific problem can be generalized and adapted readily for in many other problem areas of decision support.
The software for corpus analysis and finite-state text processing is implemented in C++. The user interface is a mock-up, but the tabular display of the results and hyperlinks back to the source can be exported as XML. The grayed-out button links to the registry of physicians for phone numbers has not yet been implemented. Responsibility to carry the prototype into actual implementation has been accepted by the BUMC ED Director of Quality with sponsorship

of the BUMC Vice President of Quality. They are currently waiting for IRB approval to create a test database of anonymized BUMC patient records for further testing and refinement of the NLP algorithm and implementation in their test environment. Options for full implementation include a stand-alone web application that can search the EHRs, or a cooperative agreement with the vendors to transfer the specifications to them for incorporation to future product release.

Conclusions, Discussion, Significance & Implications

The benefits of HIT systems for clinical care can be measurable and predictable. In order for the power of HIT to become reliably beneficial the impact on clinician's procedures and workflow must be made explicit and evaluated. Our results show how new workflow techniques can explicitly represent both the activities of care and their need to use and change information in a single, integrated model. The model can then be analyzed to reveal how care should be improved with better HIT. Although methodology research is difficult to verify because of so many uncontrolled project factors, the results show these clinical workflows were achieved methodically, as planned, and over a substantial range of outpatient care. These new techniques for model-based analysis and design have promise to reduce unnecessary HIT variation and correct the gap between HIT and the needs of clinical care. One major dissatisfaction with HIT is delays to retro-fit after expensive efforts because workflows and impact were not understood in advance. A powerful benefit of modeling is that it enables successive iterations of understanding and "to-be" approximations of the HIT solution to occur before implementation.

The explicit representation also allows both workflow and HIT to be co-designed, so they will work together as a complementary pair, and to analyze the tradeoffs that are inherent to good design. Key among tradeoffs is an analysis of better information for less need of physical resources, such as the duration of care flows and the scarce time of clinicians. Closer adherence to appropriate procedures and workflows is an important tradeoff to analyze in order to "build-in" care quality to HIT systems.

Discussion HIT must be designed to work as an integrated, efficient part of the clinical information environment. Each of the clinics we studied was challenged by poor HIT interoperability and none of their systems conformed to inter-operability standards for information sharing[34]. MATH's information dictionary provides precise requirements for just-in-time access to information that is mapped to the desired workflow and economical to implement. Clinical information, however, must also flow back and forth smoothly between the physical world and the digital world. MATH's analysis and design of HIT accounts for not only computer interoperability but also how it will be used in coordination with other types of information resources that will remain in clinics for the foreseeable future, such as paper documents, mechanical equipment, etc. In order to address these requirements MATH adapts user-centered methods to focus early on the design of an information architecture that covers all resource types.

Analysis and design must also address the way the overhead tasks that are imposed by HIT impact the quality of care. A few overhead tasks, such as logging-on or adding paper to a printer appear inevitable and should be planned as part of the clinicians' procedures for using HIT. Accidental overhead, however, is far more disruptive because it is not planned, and can even place ease-of-use in opposition to safety. Synchrony between information flow and workflow is a key principle of usability for efficient use during care[8]. Accidental overhead is also imposed on users when information from diverse resources must be integrated manually, when the organization or format does not match an appropriate cognitive strategy, or control of functionality requires excessive attention[6, 9]. If HIT information does not satisfy these requirements, then clinicians are faced with a dilemma: either perform accidental overhead tasks to compensate, or act on sub-optimal information.

Accidental overhead leads to more than mere extra work. The unintended consequence can obscure perception of the true nature of care tasks, disrupt cognition[4,5,6 &7] and inhibit the orchestration of care among team members[3]. MATH allows overhead to be identified for elimination or mitigation. A well-designed HIT application with good usability will make routine performance of safe, efficient and effective procedures the easiest course of action.

Significance Projects that cannot relate HIT to the values of care can make design decisions that are dominated by issues of technical feasibility, schedule and cost. The resulting HIT applications can have the unfortunate effect of rearranging clinical workflow and decision making by accident rather than by design[6, 7, 12]. Conversely, we believe that credible, understandable evidence of care benefit will result in increased adoption of EHR systems by supporting health care leaders in several ways. It will enable them to: Plan and compare HIT projects; Participate in concept design for the appropriate role of computing, and; Provide the visibility needed to direct HIT projects in a manner that methodically achieves improvement in the care they are responsible for and its cost.

Implications When evidence of care improvement becomes a routine factor in design, evaluation and selection of HIT, then its great power can be realized for improving care while reducing cost. One of the most practical uses of our research results is decision support for major HIT purchases. A fundamental step in the lifecycle of an EHR system is to define and validate its requirements. Decision-makers for EHR purchases need to understand how the products they consider will impact the care of patients, as well as the clinic personnel who will have to use their selection. Model-based analyses should precede product selection to define verifiable requirements for workflow improvement. They should then be included in RFPs and vendor contracts. E.g., the *to-be* workflow model should be provided as a key requirement. HIT applications should also be instrumented to record data on the evidence that justified them for ongoing evaluation or improvement after deployment[28]. These changes in purchase decisions and vendors contracting, however, will need credible justification. One important step to enable them will be to incorporate the new techniques for modeling the workflow of clinical care into existing standards, such as BPMN[14], usability testing of EHR products[35], or interoperability[34] that can be referenced in requirements documents.

Bibliography & References Cited

1. Bowman S. Impact of electronic health record systems on information integrity: quality and safety implications. Perspect Health inf Manag 2013; 10(Fall); 1c. PMID: 24159271
2. Brown CL, Mulcaster HL, Triffitt KL, et al. A systematic review of the types and causes of prescribing errors generated from using computerized provider order entry systems in primary and secondary care. J Am Med Inform Assoc. 2016 Aug 30: [Epub ahead of print] PMID: 27582471
3. Hollan JD, Hutchins E & Kirsh D. Distributed cognition: toward a new foundation for human-computer interaction research. *ACM Trans on Human-Computer Interaction: Special Issue on Human-Computer Interaction in the New Millenium* 2000 June; 7(2):174-196.
4. Zhang J. & Norman DA. Representations in distributed cognitive tasks. Cognitive Science 1994; 18: 87-122.
5. Zhang J. The nature of external representations in problem solving. Cognitive Science 1997; 21(2): 179-217.
6. Butler KA., Esposito C & Hebron R. Connecting the design of software to the design of work. Comm ACM, 1999 January; 42 (1): 38-46.
7. Butler KA, Zhang J, Esposito C, et al. Work-centered design: a case study of a mixed-initiative scheduler. Conference on Computer Human Interaction; 2007 28 April - 3 May, San Jose, CA; ACM 2007: 747-756.
8. Cain C. & Haque, S. Organizational Workflow and Its Impact on Work Quality. In: Hughes RG, editor. Patient Safety and Quality: An Evidence-Based Handbook for Nurses. Rockville (MD): Agency for Healthcare Research and Quality (US); 2008 Apr. Chapter 31. PMID: 21328740
9. Chen Y. Documenting transitional information in EMR. Conference on Computer Human Interaction; 2010, April 10-15, Atlanta, GA; ACM 2010.
10. Leviss J. H.I.T. or Miss: Lessons Learned from Health Information Technology Implementation, 2nd Ed. Chicago: American Health Information Management Association 2013.
11. Magrabi F, Sittig D, Scott JM, et al. Health information technology and large-scale adverse events. Annual Symp American Medical Informatics Assoc; 2015 Nov 14-18; San Francisco. Bethesda: AMIA; 2015.
12. Butler KA, Bahrami A, Schroder K, et al. Advances in workflow modeling. In: Zhang J & Walji M, eds. Better EHR: Usability, Workflow and Cognitive Support in Electronic Health Records. Houston: NCCD, 2014: chapter 11.
13. Bahrami A. MATHflow User Manual. Bellevue WA; Medico Systems 2015. Available at http://parvac.washington.edu/nccd/download/docs/flow-manual.html
14. Ma Y, Chen G, Thimm G. Paradigm shift: unified and associative feature-based concurrent and collaborative engineering", J Intelligent Manufacturing, special issue on Advanced Technologies for Collaborative Manufacturing 2008; 19(6): 626-641.
15. White S & Miers D. BPMN Modeling and Reference Guide: Understanding and Using BPMN. Lighthouse Point FL: Future Strategies 2008.

16. Berry A, Butler KA, Harrington C, et al. Using conceptual work products of case management to design health IT. J Biomed Informatics November 2015 Nov; 59: 15-30. PMID: 2652860
17. Butler KA., Mercer E, Bahrami A, et al. Model checking for verification of interactive health IT systems. AMIA Annu Symp Proc 2015 Nov 14-18; San Francisco. Bethesda: AMIA; 2015: 349-58. PMID: 26958166
18. Eisenstein EL, Juzwishin D, Kushniruk AW, et al. Defining a framework for health information technology evaluation. Stud Health Technol Inform 2011; 164: 94-9. PMID: 21335694
19. Banks J & Carson JS. Discrete-Event System Simulation. Upper Saddle River NJ: Prentice-Hall 1984.
20. Schroder K. MATHsim User Manual. Seattle; University of Washington 2016. Available at http://parvac.washington.edu/nccd/download/docs/flow-manual.html
21. Butler KA. Usability Engineering. In: Kent A & Williams J, eds. Encyclopedia of Computer Science & Technology vol 33. New York: Marcel Dekker 1995.
22. Butler KA, Wichansky A, Laskowski S, et al. Quantifying Usability: The Industry Usability Reporting Project. Human Factors and Ergonomics Society Conference 2002 July 1; Baltimore, MD.
23. Kieras, David (2001) Using the Keystroke-Level Model to Estimate Execution times: http://www-personal.umich.edu/~itm/688/KierasKLMTutorial2001.pdf Accessed Aug 25, 2014.
24. Kieras D. & Butler KA. Task Analysis & the Design of Functionality. In: Topi H & Tucker A, eds. Computing Handbook: Information Systems and Information Technology. Abingdon UK: Taylor & Francis; 2014.
25. Brooke J. SUS: a "quick and dirty" usability scale. In Jordan PW, Thomas B, Weerdmeester BA, et al. Usability Evaluation in Industry. London: Taylor and Francis; 1996.
26. Carroll JK, Mack RL, & Kellogg WA. Interface Metaphors and User Interface Design, in M. Helander (Ed.), "Handbook of Human-Computer Interaction", Elsevier Science; 1988: 67–85.
27. Theodore BR, Whittington J, Towle C, et al. Transaction cost analysis of in-clinic versus telehealth consultations for chronic pain: Preliminary evidence for rapid and affordable access to interdisciplinary collaborative consultation. Pain Med 2015 Jun;16(6):1045-56.
28. Welch SJ, Asplin BR, Stone-Griffith S, et al. Emergency department operational metrics, measures and definitions: Results of the second performance measures and benchmarking summit. Ann Emerg Med 2011; 58(1): 33-40. PMID 21067846
29. Deidentified clinical records used in this research were provided by the i2b2 National Center for Biomedical Computing funded by U54LM008748 and were originally prepared for the Shared Tasks for Challenges in NLP for Clinical Data organized by Dr. Ozlem Uzuner, i2b2 and SUNY.
30. Firth JR. Papers in Linguistics 1934-1951. London: Oxford University Press; 1957.
31. Karttunen L, Chanod J-P, Grefenstette G, et al. Regular Expressions for Language Engineering. J Natural Language Engineering 1996; 4: 305-328.
32. Karttunen L. Finite-State Technology. In: ed. Mitkov R. The Oxford Handbook of Computational Linguistics. New York: Oxford University Press; 2003: chapter 18.
33. Pustejovsky J & Stubbs A. Natural Language Annotation for Machine Learning: A Guide to Corpus-Building for Applications. Sebastopol CA: O'Reilly Media; 2013.
34. Health Level Seven International. Health Level Seven Standard Version 2.8.2 - An Application Protocol for Electronic Data Exchange in Healthcare Environments. ANSI/HL7 V2.8.2-2015.
35. Schumacher RM & Lowry SV. Customized Common Industry Format Template for Electronic Health Record Usability Testing. NISTIR 7742; 15 Nov 2010. Gaithersburg MD: National Institute of Standards and Technology.

6. List of Publications and Products

Payne, T, Butler KA, Ruggerio F, et al. Improving Usability, Quality and Safety: Key Lessons from Airplane Cockpit Design. AMIA Annu Symp; 2012 Nov 3-7. Video at https://www.youtube.com/watch?v=TW8JifrBJPw

Butler KA, Berry A, Walker A, et al. Patient-Centered Case Management System. AMIA Annu Symp 2014 Nov 15-19; Washington DC. Video at http://depts.washington.edu/ahrqserv/docs/P-CMS_demo.mp4.

Harrington C, Tao C, Butler KA, et al. Enhancing the TURF Framework with a Workflow Ontology. AMIA Annu Symp 2014 Nov 15-19; Washington DC.

Butler KA. Workflow for Evidence-based Health IT. A National Web Conference on Using Health IT to Support Improvements in Clinical Workflow. AHRQ 2015 July 29.

Butler KA. Modeling Usage and Change of Information in the Context of Operations. Presentation to the Standards Coordinating Council. OMG Technical Meeting; Boston: Sep 24, 2015.

Butler KA., Mercer E, Bahrami A, et al. Model checking for verification of interactive health IT systems. AMIA Annu Symp Proc 2015 Nov 14-18; San Francisco. Bethesda: AMIA; 2015: 349-58. PMID: 26958166

Butler A & Haselkorn, M. A System for Efficient Case-Management of Multidisciplinary MS Care. 28th Annual Meeting of the Consortium of Multiple Sclerosis Centers. Dallas 2014 May 28-31.

Berry A, Butler KA, Harrington C, et al. Using conceptual work products of case management to design health IT. J Biomed Informatics November 2015 Nov; 59: 15-30. PMID: 2652860

Eisenstein E. & Butler KA. Health Informatics-Enabled Workflow Redesign and Evaluation. Stud Health Technol Inform; 2015 208: 131-136.

Markour M, Butler KA, Bahrami A, et al. State Machines in OWL Ontology for Model Checking. J Computer Methods and Programs in Biomedicine; (under revision).

NASA Space Human Factors Engineering Standing Review Panel. Research Plan Review for: The Risk of Inadequate Design of Human and Automation/Robotic Integration, The Risk of Inadequate Human-Computer Interaction, and The Risk of Inadequate Mission, Process and Task Design. NASA Lyndon B. Johnson Space Center: 2016 Jan 16.

Software
An online demo of the Patient-Centered Case Management System is available at http://depts.washington.edu/ahrqserv/ncdemofinal/

MATH Software Releases available at http://parvac.washington.edu/nccd/download/docs/
- MATHflow 3.1.2342
- MATHsim 0.3.5710
- MATHview 0.3

Workflow Models available at https://depts.washington.edu/ahrqserv/)
- MS outpatient care using VistA
- MS outpatient care with VistA and P-CMS
- Pain Center outpatient care with Orca
- Pain Center outpatient care with Epic
- Pain Center outpatient care with Epic and PainTracker
- Pain Center outpatient care with Epic and Golden Sheet
- BUMC emergency care with Medhost
- BUMC emergency care with Medhost and decision support for admitting MD selection

Conceptual Work Product Models available at https://depts.washington.edu/ahrqserv/
- Priority Contact class and state diagrams in UML
- Patient-Centered Case Management class and state diagrams in UML
- Priority Contact classes and states in OWL
- Patient-Centered Case Management classes and states in OWL